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PRELIMINARY MONITORING RESULTS FROM THE PHASE II BOSTON HARBOR CONFINED AQUATIC DISPOSAL CELLS

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ABSTRACT

During the deepening of Boston Harbor in 1998/99, Confined Aquatic Disposal (CAD) cells were created beneath the shipping channel to receive sediments determined unsuitable for unconfined ocean disposal. Cell creation, material placement, capping, and monitoring approaches all built upon the lessons learned during creation of a single CAD cell during Phase I of the project conducted in 1997. CAD cells were dredged and filled using clamshell and bottom dumping barges, whereas capping involved slow release from hopper dredge equipment. Cells were dug to a maximum of -115 ft MLLW. Filled elevations, including cap, ranged from -48 to -53 ft MLLW. Sand cap effectiveness of the first three cells was intensively evaluated using several different techniques, including multibeam bathymetry, subbottom profiling, coring, and side-scan sonar in combination with specially designed tripods. Placement and capping operations were able to successfully minimize the potential for exposure of sediment contaminants to the environment. However, improvements in future efforts still could be attained by use of approaches to maximize sediment consolidation.

Keywords: Dredging, capping, dredged material, acoustic profiling, contaminants.

INTRODUCTION

A unique aspect of the 1998/1999 deepening of Boston Harbor, Massachusetts is the placement of sediments determined unsuitable for ocean disposal into below channel disposal cells. Through environmental impact statement (EIS) investigations (New England Division and Massachusetts Port Authority 1995), it was determined that, among the practicable alternatives, placement of the unsuitable sediments into below channel cells and capping with sand would have the least environmental impact. As stated in the EIS, the advantages of this alternative were:

- Confining disposal impacts to areas impacted by dredging
- Rapid recovery of biological resources to pre-existing status
- Sequestering silts near their point of origin
- Compartmentalizing disposal operations.

Thus far, the project has been successfully meeting these goals by isolating the majority of the silts below a continuous layer of sandy sediments. In the process, we are learning much more

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about this unique approach to dredged material management which can be used to improve the later cells created in the Boston project, as well as planning for similar projects elsewhere.

Project Background

Phase I. The Boston Harbor Navigation Improvement Project (BHNIP) involves deepening of the main ship channel (in the Inner Confluence and the mouth of the Reserved Channel), three tributary channels (Mystic River, Chelsea Creek, and Reserved Channel), and eight private berth areas in Boston Harbor (Figure 1). All of the channels will be deepened to -40 ft MLLW, except for Chelsea Channel, which will be dredged to -38 ft MLLW. The berths will be dredged to -35 to -45 ft MLLW, for a combined total of 2.1 million yd^3 of material. About 800,000 yd^3 of these sediments are unsuitable for unconfined ocean disposal and are to be placed into the below channel cells. BHNIP is a joint project between the US Army Corps of Engineers, New England District (NAE) and the local sponsor, the Massachusetts Port Authority (Massport).

For the first phase of the BHNIP, an in-channel CAD cell was constructed for containment of unsuitable dredged material from shipping berths at Conley Container Terminal in South Boston by Weeks Marine (Camden, NJ). The dredged, fine-grained sediments were disposed into the CAD cell, and then capped with sufficient sand to cover the deposit with a 3 ft thick layer of clean, granular material. The cell was excavated below the maximum channel depth anticipated for Boston Harbor (-40 ft MLLW) to an average total depth of -57.5 ft. First, the unsuitable maintenance material from the cell area was removed and stored in a barge. Cell excavation continued into Boston Blue Clay (BBC), a homogeneous, high strength greenish gray clay with low water content and low permeability (CDM 1991). The approximate dimensions of the CAD cell were 500 ft long (north-south) by 200 ft wide (east-west).

Monitoring results from this first disposal cell resulted in several recommendations to improve the CAD capping process in Phase II of the project (Murray et al. 1997). The recommendations to modify the requirements for dredging and disposal operations were designed around the primary concerns raised by the monitoring observations, including lack of spatial coverage of sand, variable thicknesses of sand, and potential mixing between sand and dredged material (ENSR 1997; Murray et al. 1997). The recommendations included (1) requiring the contractor to use a moving barge or vessel to slowly dispose the sand over the silt material; (2) increasing the time between silt disposal and capping to allow greater consolidation to increase the bearing capacity of the dredged material; and (3) continuing to use multiple methods to assess cap coverage, including subbottom acoustic profiling and coring.

An important project component affecting dredging, disposal, and capping was the Water Quality Certification and its conditions. In particular, relative to capping success, were the requirements to use a water-tight bucket and a limitation on the time prior to cap placement. The requirement for a watertight bucket was related to concerns surrounding dredging resuspension, but it had potential for the negative consequence of increasing water content of the silty unsuitable sediment. The requirement to cap cells within 30 to 60 days was driven by a concern

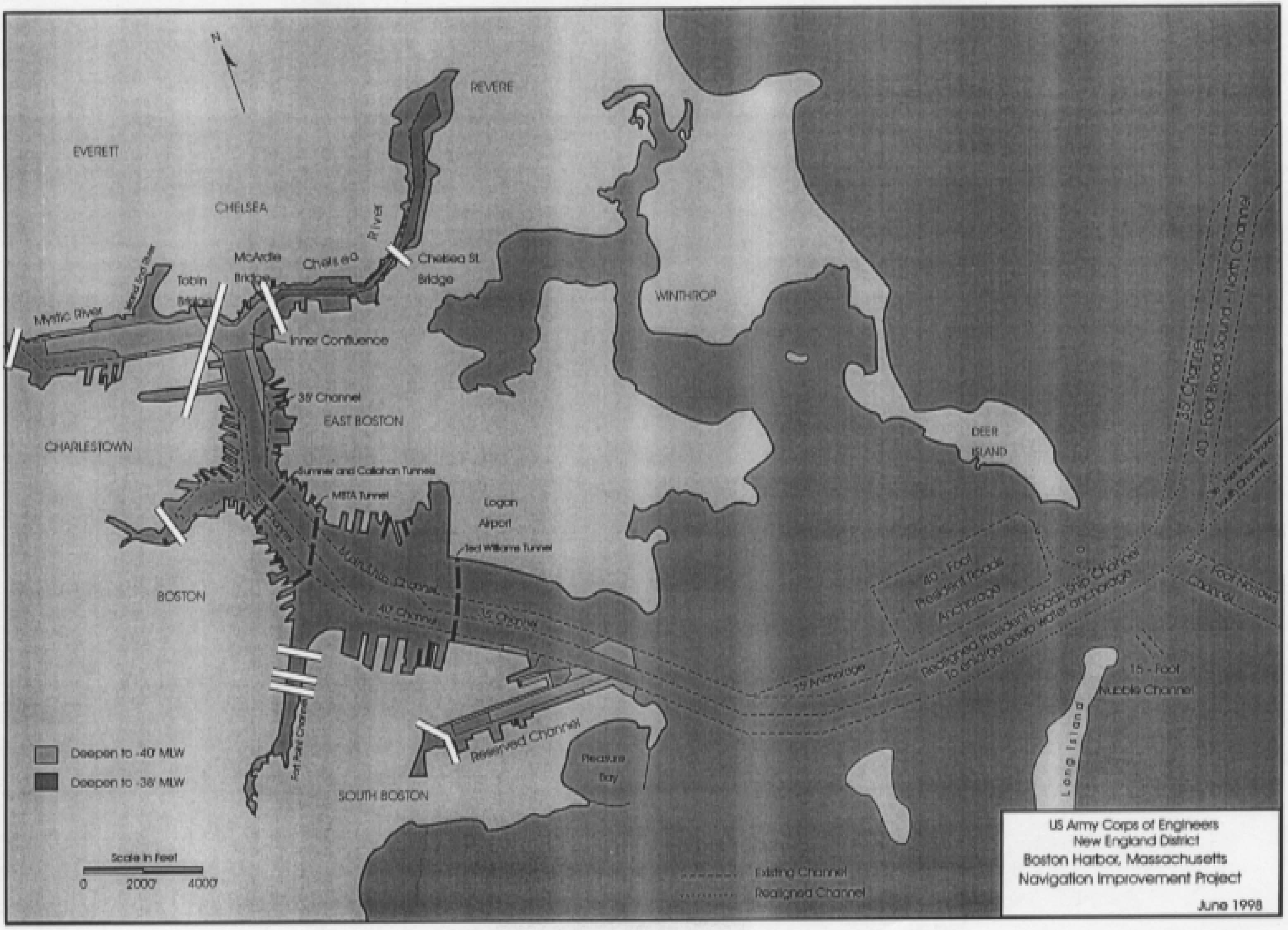

Figure 1. Boston Harbor Navigation Improvement Project location of main channels and berths to be dredged (from NAE and Massport 1995).

to minimize the length of time the cells were left open. However, this requirement coupled with use of the water-tight bucket increased concerns regarding the ability to cap these sediments.

Phase II. The first stage of Phase II involved the creation of three disposal cells labeled M4, M5, and M12 (Figure 2). Cell M5 was the smallest of these three cells and was the first to be created and filled (Table 1). Filling of the cells was accomplished over a period of 4-6 weeks. The consolidation time prior to capping was 30 days for M12, 33 days for M4, and 52 days for M5, however, the majority of silt was placed into M5 and M12 83 and 56 days before capping, respectively.

Cap material was placed using a hopper dredge with sandy sediment dredged from Cape Cod Canal. The material dredged from the canal met the Water Quality Certification requirements: <10% passing the #200 sieve (silt and clay), and <10% retained by the #4 sieve (coarse gravel/pebbles), and was dominated by medium-coarse sand. The material was placed in each cell following each hopper trip between Cape Cod and Boston Harbor. Capping operations were conducted between 11 and 18 November 1998. Cap verification data were collected prior to, during, and following cap placement (Figure 3).

Cap placement was estimated using information collected by the dredging contractor, Great Lakes Dredge and Dock (GLDD), on hopper dredge position, draft, and ship's heading which were recorded every five seconds. The draft measurements were converted into mass loss, and then used for estimates of the tonnage of sand released over each CAD cell throughout the disposal period. In addition, GLDD estimated the volume of sand per hopper load by measuring the height (sounding) of sand in the hopper, and then converting relative to the known volume of the hopper.

Generation of capping tonnage and sand thickness plots for the CAD cells were developed by Science Applications International Corporation (SAIC), one of the monitoring contractors to GLDD, following a multi-step procedure (Murray et al. 1999). The forward and aft position of the hopper. calculated from each five second record of the DGPS antenna position and ship's heading, were plotted as line plots relative to the location of the boundaries of the CAD cell (Figure 4). In order to map the resulting thickness of sand over the cell, an assumption was made that the sand was dispersed from the hopper evenly along the length of the vessel. Each hopper position was divided into 15 bins along the length of the hopper (150 ft), and the released tonnage of sand was distributed over the 15 bins using an automated routine.

The individual points were reduced to a gridded matrix of cells for each load, using 30 ft x 30 ft grid cell sizes, representing a cumulative tonnage of sand. The gridded matrix for each load was compiled by summing the tonnage values for all disposal points falling within the boundaries of each individual grid cell (Figure 4). The cell size ranges were selected by assuming the spread of material beneath the hopper during disposal. The actual tonnage dispersed for each hopper load had to be corrected for the weight of water entering the hopper during disposal. The correction factor was based on an estimate of the difference between an open, empty hopper and a closed, empty hopper containing no water (800 tons). The individual tonnage grids compiled for each hopper load were in turn cumulated for all of the loads prior to the interim capping surveys, and for the total tonnage of sand. These cumulative tonnage plots were mapped for each cell. The

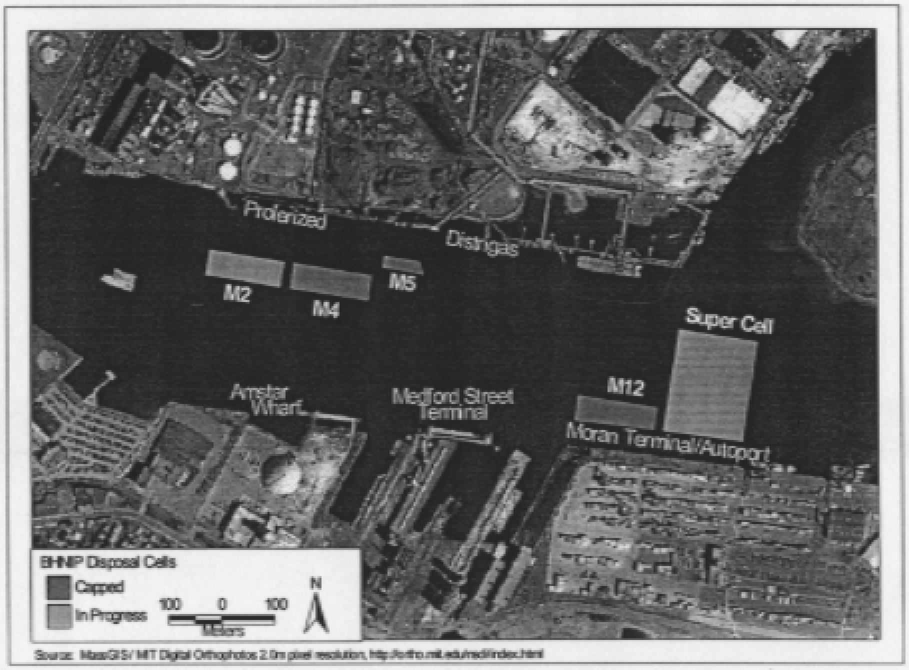

Figure 2. Location map of the initial Phase 2 confined aquatic disposal cells in the Mystic River.

Table 1. BHNIP CAD Cell Summary Table

Cell	M4	M5	M12
Physical Characteristics			
Area of cell (ft^2)	63,253	26,121	60,875
Average pre-disposal elevation (ft MLLW)	-85	-80	-110
Total capacity (yd^3)*	55,066	27,500	85,450
Total silt placed (yd^3)	49,800	30,100	78,100
Total material (silt and sand) placed (yd^3)	62,974	35,518	91,447
Filled elevation (ft MLLW, as of 12/98)	-53	-48	-53
Capping Operations			
Total sand placed - draft calculations (yd^3)	13,557	5,396	13,528
Total sand placed - measured in hopper (yd^3)	13,174	5,418	13,347
Error in volume calculations (% difference)	2.91%	-0.41%	1.36%
Silt:cap ratio	3.8	5.6	5.9
Material Thickness and Distribution			
Total average silt thickness (ft)	21.3	31.1	34.6
Total average sand thickness (ft)	5.6	5.6	5.9
Average silt over sand (ft)	3.9	2.5	1.1
Percent silt covered by sand	82%	92%	97%
Consolidation time between silt disposal and cap (days)			
Primary**	33	83	56
After all loads	33	52	30

*If filled to -45 ft MLLW.

**Time was calculated from the time the majority of material was placed; see Figure 3.

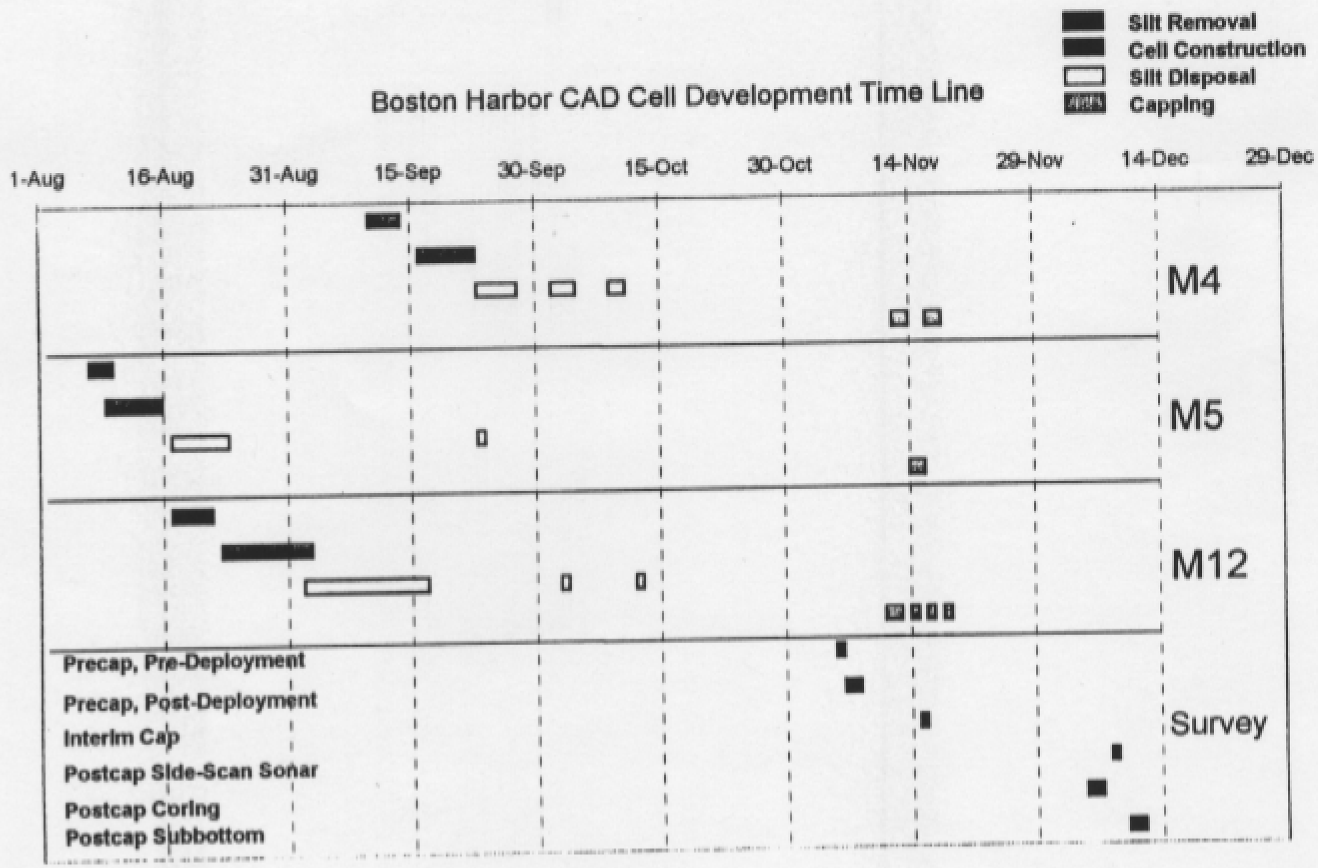

Figure 3. Sequence of dredging, disposal, and monitoring operations for the first three CAD cells.

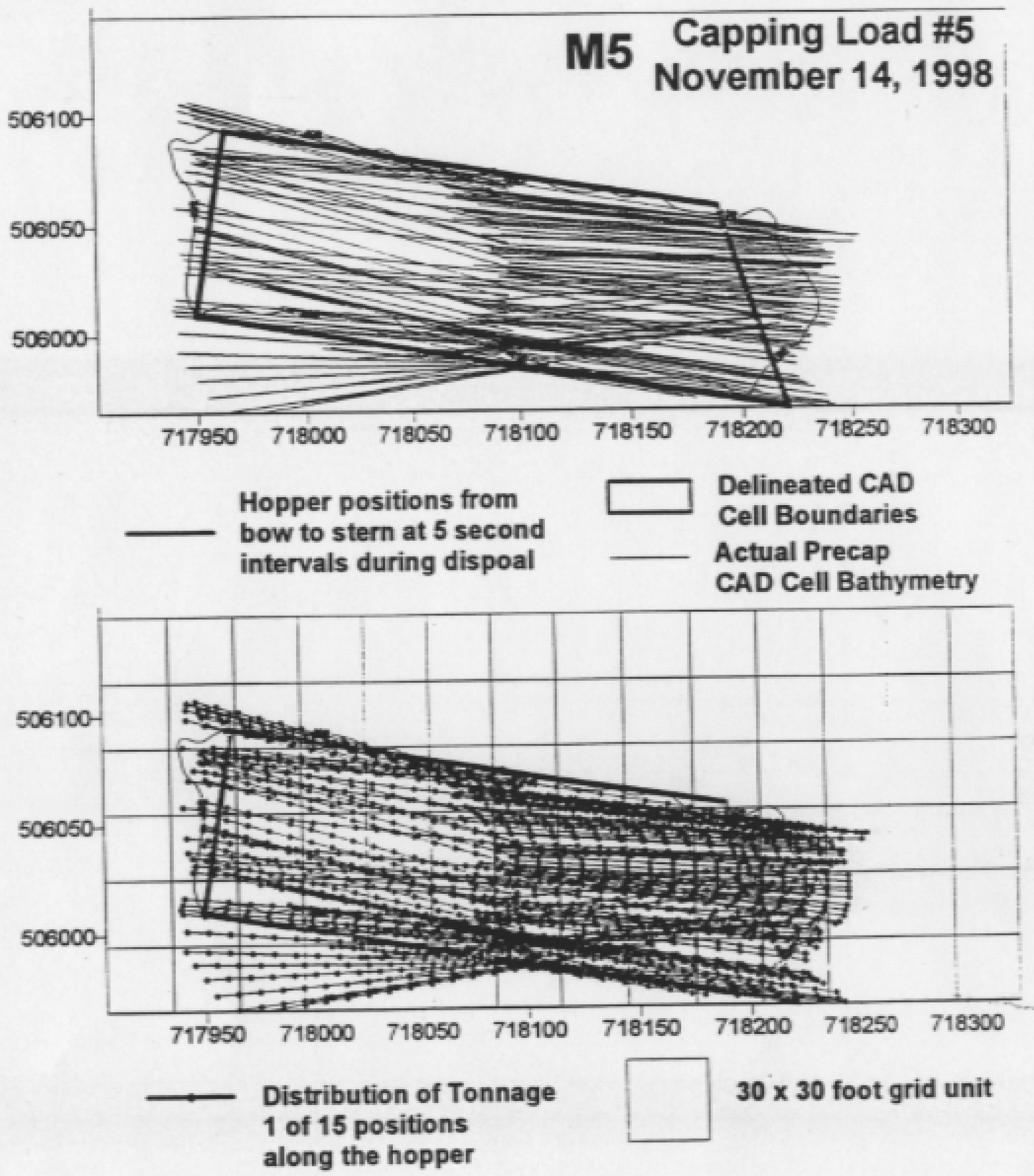

Figure 4. The upper map shows the hopper locations during disposal. The lower map shows the distribution load tonnage across the length of the hopper with respect to the 30 x 30 ft grid units.

cumulative tonnage grids were then converted to volume (yd^3) by assuming a value for the bulk density of the Cape Cod sand (2 g/cm^3; Hamilton 1971). The cumulative volume of sand in each cell was calculated by summing over each grid, and the results were compared to the GLDD estimates using actual measured sand thickness in the hoppers. The error between these two independent methods of estimating cap volume was <3%, providing confidence in the volume data (Table 1; Murray et al. 1999). Finally, the volume of sand was converted to sand thickness over the cell (in ft) by dividing by the area of the grid.

CAP MONITORING

There were several survey activities conducted to support cap verification and assessment. Ocean Surveys, Inc. (OSI) collected vibracoring, bathymetry, and subbottom data in support of the required cap monitoring for GLDD (OSI 1999). SAIC conducted several surveys in support of NAE studies of cap monitoring techniques, including placement of cap measurement tripods (discussed below), grab sampling, gravity cores, and side-scan sonar (Figure 3; Murray and Saffert 1999). Detailed methods and equipment used for these surveys can be found in these separate reports whereas brief summaries are provided here.

Pre- and Interim-cap Gravity Core and Grab Sample Operations

A series of 16 sediment grab samples were collected from the three CAD cells in Mystic River on 6 November 1998 prior to capping, with eight samples from M12, and four from both M4 and M5 (Murray and Saffert 1999). During the interim cap survey on 15 November, 16 sediment grab samples were collected from the three CAD cells in Mystic River, with eight samples from M12, three from M5, and five from M4. The grab samples were brought on deck, described, and digitally photographed. Sub-samples of the sediment were collected and placed in double-bagged freezer storage bags, labeled, and archived for potential future grain size analyses.

Prior to sand disposal, SAIC also collected sediment gravity cores from CAD cells M12, M5 and M4 on 6 and 7 November. The gravity corer was used to collect cores up to 10 ft in length. A total of 16 gravity cores, with penetration ranging from 65 cm to 275 cm, were collected, capped and stored vertically (Table 2). Six cores were taken from both M4 and M12, and four were collected from M5. The cores were collected in anticipation of providing support for a geotechnical study of the material to be conducted by the U.S. Army Corps of Engineers' Waterways Experiment Station (WES). As one measure of consolidation, the height of the sediment within the cores was measured on 14 January 1999 and compared to the initial sediment levels.

Pre-, Interim-, and Postcap Side-Scan Sonar Survey Operations

Side-scan data were collected for two overall objectives: to test the ability to acoustically "see" cap verification tripods in the cell (Murray and Saffert 1999), and to evaluate the surface texture and variation during several stages of capping. Tripods were placed immediately prior to capping, with reflective plates designed to provide an indication of the actual thickness of sand relative to the plates during each side-scan survey. Two side-scan surveys were performed before capping operations began. The first occurred on 5 November before the capping tripods were deployed in the cells, and the second was performed after tripod deployment on 6 November. An interim-capping survey was conducted on 15 November, and a postcap survey was completed by 8 December. Side-scan data collected at 100 kHz and 500 kHz, when possible, were analyzed. The collection of 500 kHz data was commonly hampered by turbidity in the water column. Additional equipment, positioning, and processing information is available elsewhere (Murray and Saffert 1999).

Postcap Bathymetry and Subbottom Operations

Bathymetry and subbottom operations were conducted from 10-12 December 1998. An EdgeTech GEO-STAR "chirp" subbottom system (4-24 kHz) was used along tracklines spaced 30-50 ft apart. Bathymetric data were collected simultaneously with a dual-frequency depth sounder (200/24 kHz). Vertical records produced by the GEO-STAR system were produced as figures (OSI 1999) and excerpted for the purposes of this report. Additional details on survey and data processing methods are published and available elsewhere (OSI 1999).

Subbottom seismic profiling is a standard technique for determining the presence of sediment layers below the sediment/water interface. The X-star system emits a swept-frequency pulse; the frequency of the transmitted pulse changes linearly with time, and is therefore called a chirp system. The depth of penetration and the degree of resolution are dependent on the frequency and pulse width of the seismic signal, and the characteristics of the penetrated material.

Postcap Vibracore Operations and Grain Size Analyses

OSI collected 15 vibracores from pre-selected locations at the three CAD cells on 5-6 December 1998. The cores were obtained using an OSI Model 1500 pneumatic vibratory corer equipped with a 10 ft long core barrel. The cores were transported to OSI (Old Saybrook, CT), where they were processed. Each core liner was split along two lengths of the core, and the liner was removed to reveal the core. The cores were described and photographed.

Sediment samples were collected for grain size processing approximately every six inches. A subset was selected for processing and used to aid the interpretation of cap placement. Grain size data were provided as percent dry weight retained by a series of sieve fractions. For the purposes of reporting, the combined sand and gravel fractions (retained by the #200 sieve) are reported together. Physical descriptions of the grain sizes were assigned based on the Wentworth (1922) scale.

RESULTS

Cap Coverage: Subbottom Results

The subbottom data indicated different conditions in the three different cells and are discussed independently for each cell. First we will provide a brief description of the subbottom data and the inferences that can be made about the sediments of the cell from the data.

The ability to detect subbottom layers is dependent on the acoustic impedance contrast between sediment layers or between the water column and the surface sediment layer. For example, the acoustic reflector from a coarse-grained sediment surface layer will be darker relative to that of a finer-grained surface layer because of the higher contrast in acoustic impedance between water and sand. In general, sound penetrates further into fine-grained sediment because the impedance of high-water content silt and clay is closer to that of the water column. Penetration of sound into the subbottom sediment is both a function of system frequency and acoustic impedance between the sediment layers. Acoustic impedance, the product of velocity and density of sound in a layer, is also affected by differences in surface roughness, porosity, and grain size, among other factors (Hamilton 1970; LeBlanc et al. 1992).

In most of the images, a series of horizontal reflectors are apparent outside of the cell area reflective of the natural geology of Boston Harbor. These sediments are a combination of BBC and glacial till (material left after a glacier melts) that were deposited in a nearshore marine environment that existed in the Boston area during an interglacial period about 18,000 years ago (CDM 1991 and references therein).

Subbottom Results from Cell M4. The subbottom data from M4, with groundtruth data from cores (discussed below), indicated a consistent layer of denser material over at least 90% of the cell underlying 2-4 ft of acoustically transparent material (Figure 5; OSI 1999). This result indicates that the reflector was due to a laterally continuous impedance contrast between the surface 2-4 ft transparent layer and the underlying material. The presence of the transparent layer is consistent with the bar checks conducted on site, showing 2-4 ft of low strength material through which the bar consistently sank (OSI 1999). The subbottom data also indicated that the vertical distribution of the denser layer in M4 was quite variable, with indications it was present down to 10-12 ft in some areas of the cell (Figure 5). In combination with coring data, these results were interpreted to indicate that there was a thick, continuous sand zone across the cell overlain by a thinner layer of high water content silt (Murray et al. 1999).

Subbottom Results from Cell M5. The subbottom data from M5 indicated a consistent layer of denser material over at least 90% of the cell underlying the acoustically transparent material (OSI 1999), and was generally similar to that of M4. The thickness of the dense (sandy) layer was more constrained than in M4, with a more consistent boundary at the base of the layer (Figure 6).

Subbottom Results from Cell M12. In M12, there was no consistent reflector that could be traced across the cell with as much confidence as in M4 and M5, indicating more horizontal variability. There was, however, a similar sand zone of higher reflectivity across the top of M12. Much of the subbottom acoustic information below the surface layer was lost, indicating less sound penetration to depths below the sand zone. Further evidence of the presence of a sand layer was the high amplitude reflector on top of the data record.

This result was more similar to the results of Phase I. In that phase, sand was present at the surface of part of the cell, but was not horizontally continuous across the cell. In the area of the sand, there was a series of discontinuous internal reflectors indicating a heterogeneous deposit,

CELL NO. 4
LINE NO. 6-003

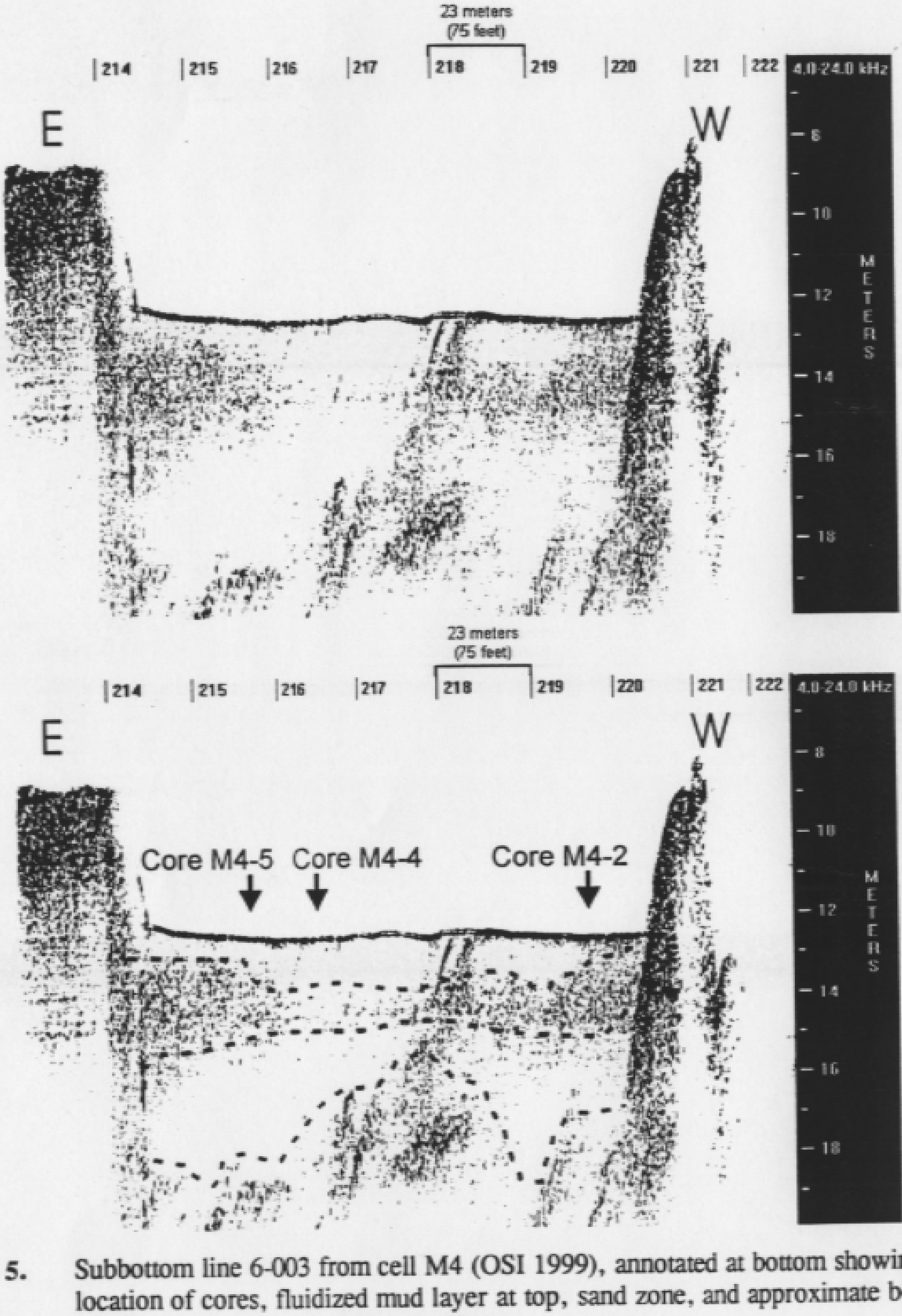

Figure 5. Subbottom line 6-003 from cell M4 (OSI 1999), annotated at bottom showing location of cores, fluidized mud layer at top, sand zone, and approximate bottom of cell. Note reversal of East and West.

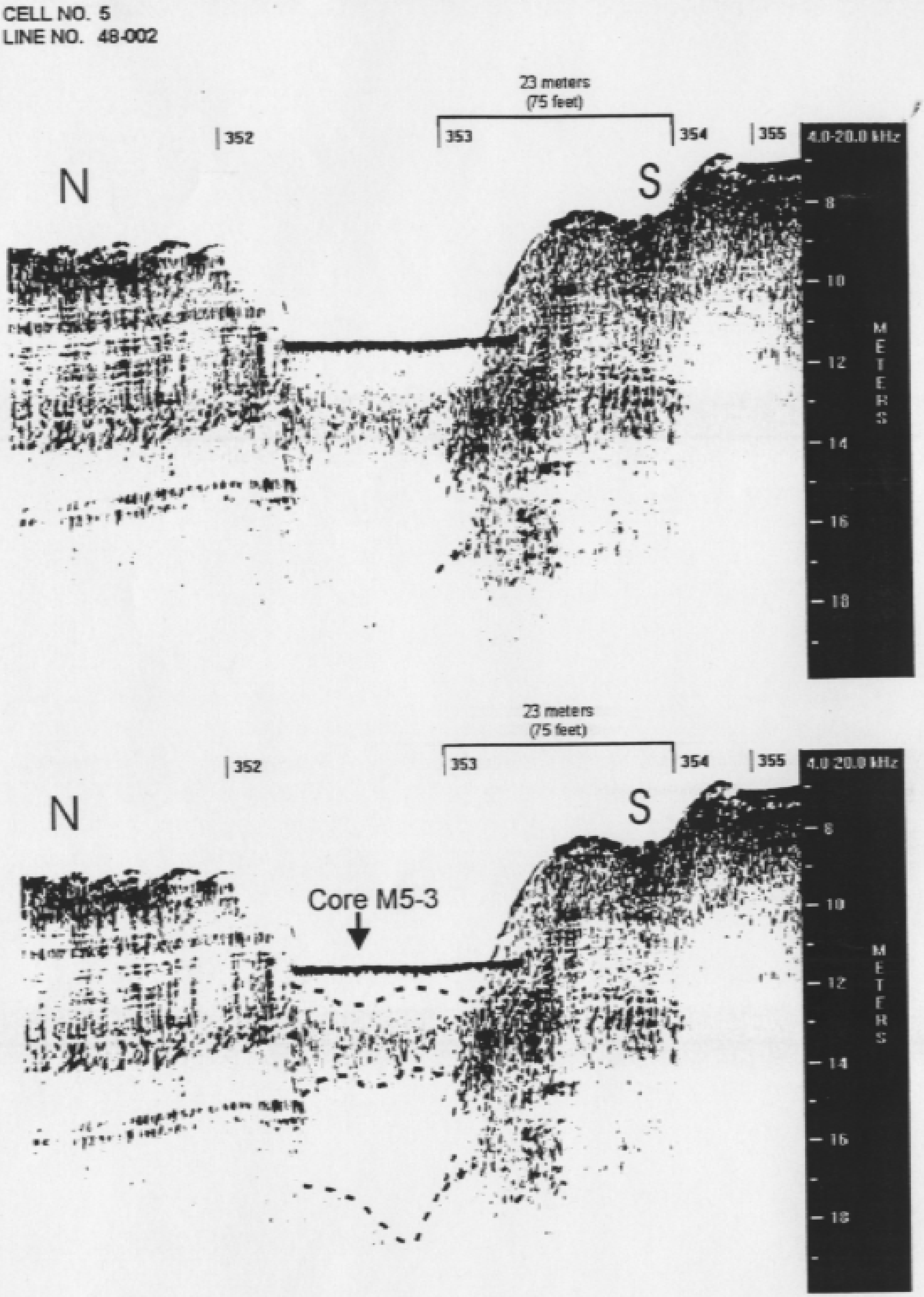

Figure 6. Subbottom line 48-002 from cell M5 (OSI 1999), annotated at bottom showing relative location of cores, fluidized mud layer at top, sand cap and approximate bottom of cell.

potentially caused by mixing of sand and silt in that cell. Prior acoustic work over dredged material has indicated that the acoustic signature of dredged material is distinct because of sound loss due to scattering and refraction, indicative of the heterogeneous nature of the deposit (Bokuniewicz et al. 1976; Schock et al. 1992; Murray et al. 1995).

Consolidation State of the Dredged Material: Grab and Core Descriptions

Precap Grab Samples. The grabs collected prior to capping commonly consisted of black silt with watery or "soupy" texture. Two grabs in M12 came up with Boston Blue Clay in them due to their proximity to the cell edge. Several grabs were described as having some texture, potentially indicating a slightly more advanced state of consolidation, including all of the grabs from M5 and two of the grabs from M4.

Interim-Cap Grab Samples. The grabs collected during the interim capping survey commonly consisted of black sandy silt or silty sand. One grab from M12 (M12-3) was described as gray sand; this grab was located outside of the cell boundaries. All of the grabs collected from M12 and M5 had some sand content, while four of the five grabs from M4 had only a trace to no sand. In addition, three of the five grabs collected from M4 were still relatively unconsolidated, described as "very watery."

Precap Gravity Cores. Because the precap gravity cores were collected for another study to be conducted by WES, they were archived for future potential geotechnical testing. They were stored vertically, and thus the material in the cores continued to consolidate after collection. This in-core consolidation data were evaluated to provide a qualitative estimate of the relative consolidation state of the material in the three cells prior to capping. Total consolidation of the sediment collected in the cores ranged from 18.7 to 30.7% from M4, 10.0 to 25.6% from M5, and 13.8 to 17.6% from M12. The average consolidation for each cell also was calculated. M4 had the overall highest average in-core consolidation value (26.5%). The consolidation of M5 and M12 was similar (15.7, 15.8%). The average value of M5 was skewed, however, by the single high value of Core 18B, the shortest core recovered (82 cm). The re-calculated average consolidation for M5 excluding Core 18B was 12%.

Surface Texture: Side-Scan Sonar Results

The primary goal of the side-scan sonar surveys was to test the use of the tripods for monitoring cap thickness. Although the goal of visualizing the cap thickness relative to the measurement tripods was confounded by poor water clarity (the tripods were obscured by the overlying watery, silt layer), the data were useful to document the surface topography of the cells during the various stages of capping. The surface of the cells during the precap surveys was commonly smooth and featureless, in contrast to the area surrounding the cells which was pock-marked from spud marks and dredge cuts. The cell itself commonly had consistently weak backscatter, indicating a flat, featureless surface topography, probably due to the presence of the fluidized layer on top. Results of grab sampling confirmed the presence of high water content fine-grained sediments at the surface of the cells during the precap survey.

Results during the interim survey were similar to those of the precap survey. M12 was the only cell to show some variation in surface topography. The eastern end showed stronger backscatter and some topographical variability relative to the western end, consistent with the depositional pattern. The postcap side-scan results were similar, in that M12 showed the strongest evidence for sand at the surface of the cell, including stronger backscatter from the cell itself, and linear features that could be associated with cohesive sediment or sand.

Discrete Cap Thickness Measurements: Vibracore Results

Vibracore results included both visual descriptions of the lithology and discrete grain size data. Comparison of these data indicate that the visual descriptions tended to underestimate where sand was present in the core, often identifying portions of the core that were primarily sand as silt. However, whenever the visual description was sand this was confirmed by the grain size data. For this reason the cores were interpreted using a combination of these two data sources. Core locations generally were selected in areas of predicted thinner cap, therefore the cap thickness measured in the cores as discussed below are minimum thicknesses. The stratigraphy (layering) of the cores was different for the three cells, and will therefore be described separately. In the following figures, core results are shown in relation to their location on the calculated thickness of sand (based on hopper draft and position data as described above).

Core Results from Cell M4. Six cores were collected from M4, ranging in length from 7.5 to 8.3 ft (Figure 7). All cores had evidence of a sand layer ranging from approximately 1 to 5 ft thick. Grain size in this layer was greater than 50% sand, and predominantly 70-95% sand. In four of the cores, the thickness of the sand layer was likely an underestimate since the bottom of the core ended in sand. The upper portion of the cores contained a layer of mixed sand and silt or just silt ranging from 0.6 to 6.3 ft thick, with an average thickness of 3.9 ft (Murray et al. 1999). These data were consistent with the subbottom data showing the sand zone overlain by a thinner acoustically transparent material.

Core Results from Cell M5. Three cores were collected from M4, ranging in length from 7.4 to 8.1 ft (Figure 8). All cores had evidence of a sand layer ranging from approximately 2.6 to 4.4 ft thick. Grain size in this layer was predominantly 60-95% sand. In Core M5-3, the sand layer had an imbedded 6-in layer of sandy silt (Figure 8), although the thickness of the sand unit in M5-3 was a minimum because the sand extended to the base of the core. At the base of the other two cores from M5 was black fine-grained sediment. Overlying the sand zone was a layer of silt and sand with an average thickness of 2.5 ft. Again, these data are consistent with the subbottom data showing the consistent sand zone over the area of the cell overlain by a thinner acoustically transparent material.

Core Results from Cell M12. Six cores were collected from M12, ranging in length from 7.0 to 8.4 ft. All cores had evidence of a sand layer ranging from approximately 2 to 5 ft thick, but with a more variable presence of silt layers within the sand zone. As opposed to M4 and M5, the sand unit in three of the six recovered cores (M12-3, M12-5, M12-6) was present at the top of the core, with thicknesses of 2 to 5 ft (>50% sand; Murray et al. 1999). The sand unit at the top of M12-3 was interspersed with 0.6 ft of siltier sediments (Figure 9). The stratigraphy of the other three cores recovered in M12 was more similar to M4 and M5, with the presence of a fine-

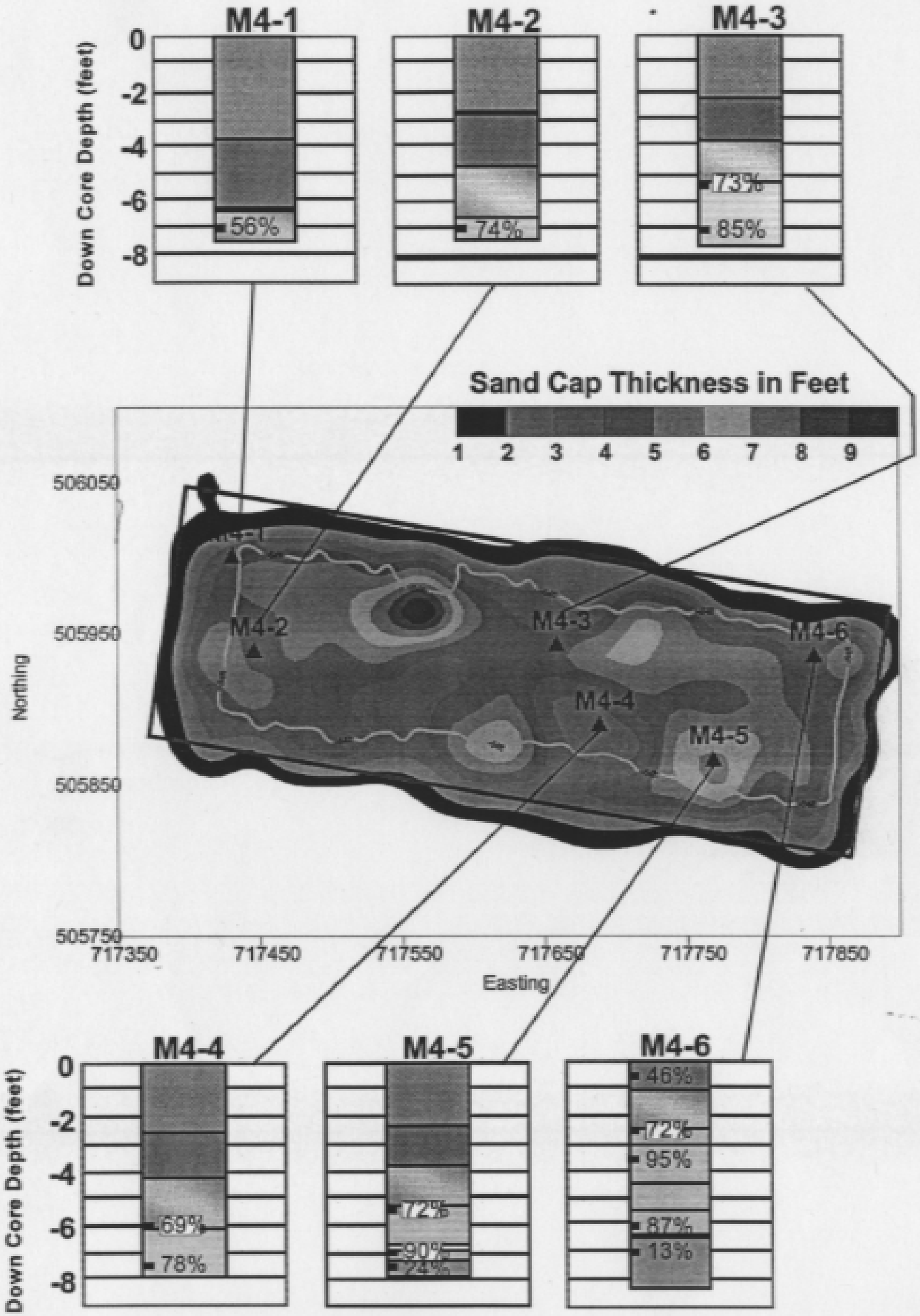

Figure 7. Calculated sand thickness of cell M4 with interpretive core descriptions and complete grain size results, see legend on Figure 8 for core descriptions.

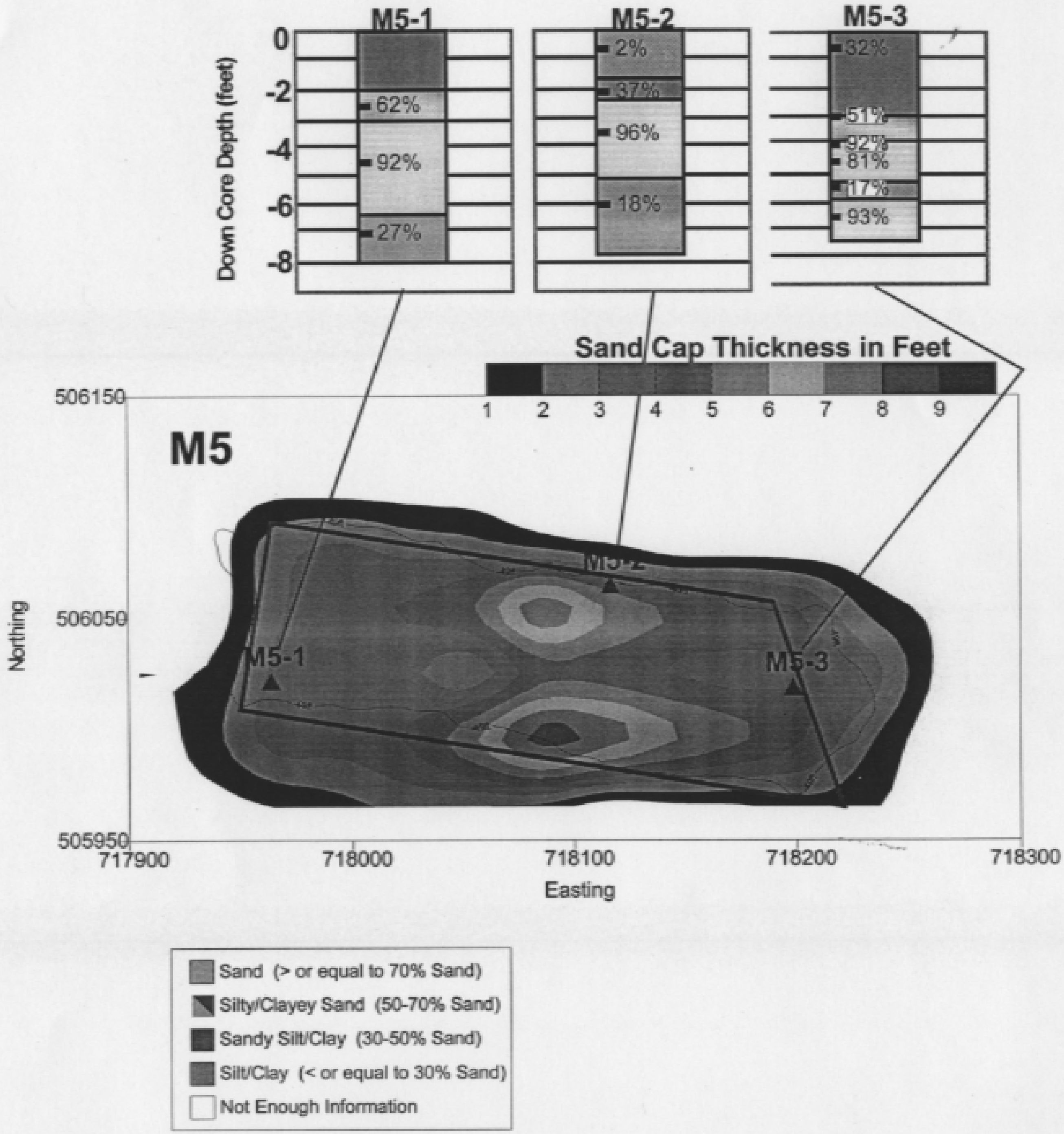

Figure 8. Calculated sand thickness of cell M5 with interpretive core descriptions and complete grain size results.

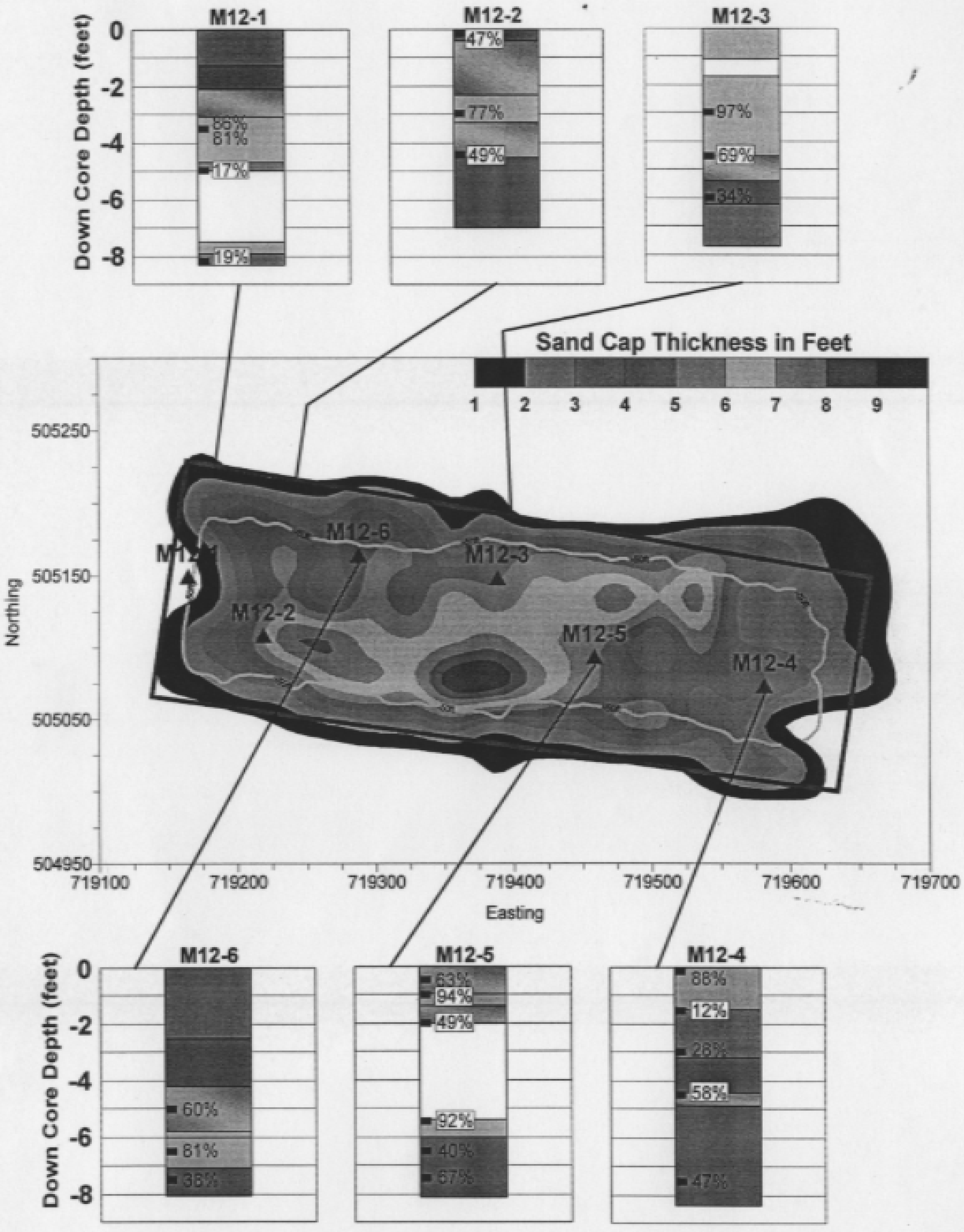

Figure 9. Calculated sand thickness of cell M12 with interpretive core decriptions and complete grain size results, see legend on Figure 8 for core descriptions.

grained layer with sand increasing down-core. The thickness of the top unit, where present, ranged from was highly variable, ranging from 0.4 to 4 ft. The base unit of all of the cores from M12 was a black silt and clay with variable sand. Actual grain size samples collected from this unit indicated a sand fraction ranging from 34 to 67%.

DISCUSSION

The placement and capping operations of the first three Boston Harbor Navigation Improvement Project Phase II confined aquatic disposal cells have met the EIS objective to minimize future exposure of sediment associated contaminants to the environment. The unsuitable sediments were successfully dredged and placed into the in-channel disposal cells, and a continuous zone of sand was placed across the cells. The average thickness of the sand zone was 8 ft in M4 and M5; core data provided minimum sand zone thicknesses in each cell, ranging from 3.2-3.8 ft. However, on top of this sand layer, a relatively high water content sediment was present over much of the cells, especially in M4 and M5. While some of this sediment may have been deposited into the cells from the higher, elevated harbor floor (Table 1), it seems evident that much of it may be sediments that were not trapped beneath the sand cap. This inability may have been greatly influenced by the requirement of the project to use a water tight clamshell bucket and the relatively short time allowed for consolidation. The experience gained on these first three cells is being used to modify the approach for the remainder of the project and will be useful in planning similar efforts elsewhere.

Though these CAD cells do not match the classic conceptual design of a capped dredged material site, it is important to evaluate their performance based on the original expectations for this disposal alternative, as discussed in the EIS. In this respect, (1) the cells have minimized disposal impacts to the same area as the dredging impacts; (2) the silts are sequestered near their point of origin; (3) recovery of biological resources to pre-existing status can be expected to occur rapidly; and (4) the disposal operations have been compartmentalized in that disposal has involved a minimum of logistics, fossil fuel use, and air emissions.

It is also important to recognize that the requirements of the Water Quality Certification were not designed to optimize capping, rather they were focused on minimizing short-term impacts to water quality and biota. This doesn't mean that the Water Quality Certification goals were mis-directed, but it only illustrates the kinds of trade-offs that need to be considered and prioritized when designing and regulating such projects. Had the conditions focused on maximizing capping, then the use of a conventional open bucket along with consolidation times of 4-6 months or more (or some monitoring to help assess when capping could begin) would likely have been among the needed requirements.

The disposal cells will provide excellent isolation of the unsuitably contaminated sediments, even those that may not have been trapped beneath the sand. The effective isolation of the sediment-associated contaminants derives from the expected accumulation of sediment in the remaining volume of the cell, the relatively small volume of pore water (and associated contaminants) that will be released during consolidation, and the very slow process of diffusion. In addition to the physical isolation provided by the presence of the sand zones, accumulation of sediments into the cells, which are 6-10 ft below the surrounding channel bottom, will provide additional long-term isolation. These disposal cells are expected to act as sediment traps, just as the channels themselves fill in over time. This added sediment, even if only a few millimeters per year, will outpace chemical migration of contaminants by orders of magnitude (Murray et al. 1994). It is this continued sedimentation that will effectively isolate even those sediments that may not have been trapped below the sand layers.

Short-term pore water losses, due to consolidation of the deposit, result in release of contaminants that will be at concentrations similar to elutriate measurements. Typically these represent a very small portion of the overall contaminant load of sediment. As an illustration, assuming a 3 ft of consolidation over 8 weeks, this will produce 27 gallons of pore fluid per square yard. Even if this 27 gallons were expelled in an hour and mixed into just 12 ft of the water column above the cell with the tide running at 0.5 ft/sec, the dilution capacity would be 6000 times. Obviously, at the expected consolidation rates lasting weeks, the potential for water quality impacts is negligible.

In the longer term, diffusion over relatively short distances of a few ft can take hundreds to thousands of years to even begin to have an effect. In an example provided by Murray et al. (1994), they show that diffusion of copper (a relatively soluble contaminant) from a distance of about 3 ft below the surface of a deposit will take more than 2500 years for the first atoms to reach the surface. Considering that these disposal cells have sediment thicknesses of 35 to 65 ft, diffusion losses are predicted to be extremely small. The contaminants are beyond all reasonable chance of impacting the environment.

RECOMMENDATIONS

Experience gained from the first four cells of the Boston Harbor Navigation Improvement Project lead to a number of recommendations that will allow continued improvement in the construction and monitoring success of this management approach. For optimizing capping, techniques that maintain the consolidation status of the sediments should be considered, such as use of an open clamshell bucket and adequate consolidation time. At present, we know of no quantitative measure that can be used to determine readiness for capping and until there is further research into this area we recommend a time period of no less than 4-6 months, coupled with grab sample surveys to visually assess consolidation status. We were able to observe discernable differences in the cohesive state of the sediments in each of the cells that seemed consistent with the amount of time each had undergone consolidation.

Even when using these approaches to maximize consolidation, it is reasonable to expect that CAD cells will maintain an upper component of high water content sediment for some considerable time. Unlike level bottom capping, where the higher water content sediments end up out in the apron, a CAD cell traps these sediments into a confined pool. In the apron of a level bottom capping project, these sediments will tend to consolidate relatively quickly due to the large surface area over which they are spread. Further, during capping operations they will tend to be overspread by similar higher water content sediments that are derived from the capping material. Whereas in a CAD cell, these sediments will maintain their condition for a much longer time, because any water expelled from the deeper consolidating sediments will seek the least resistant route out: up. For this reason, unless the CAD cell can be kept uncapped, a certain degree of mixing and possibly mass movement of low strength material back above the cap should be expected. (Note: the authors believe that the whole question of the need to cap such cells needs much further discussion. In many cases, the benefits of natural capping via ambient sedimentation may serve to prolong the need for future maintenance and a cap may simply decrease this benefit.)

Monitoring interpretations of CAD cells clearly benefit from using multiple approaches with emphasis on subbottom acoustic surveys and coring. Among the items to be considered are the following for monitoring and future research are:

- Vibracores collected for cap verification should be selected randomly, to reduce bias towards thicker or thinner areas of cap.
- Longer vibracores should be collected (20 ft).
- Vibracores should be split in half prior to description to minimize the effect of fluid silt between the core liner and core obscuring the visual presence of sand.
- Electronic core logging should be considered to measure the geotechnical properties of the entire core, with discrete samples collected for groundtruth. These data would be useful to quantify sand gradients and groundtruth subbottom data (speed of sound measurements).
- Additional precap geotechnical data should be collected, potentially including consolidation and in situ pore pressure measurements to be used as guidance for consolidation rates.
- Over the long-term, subsequent subbottom surveys would contribute useful data to monitor the continued physical isolation provided by the sand zone.
- Theoretical consolidation data, using available physical properties of the dredged material and depth of the cell, should be investigated to improve predictions of the consolidation time required.

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